CLARREO RS CDS Update

K. Thome, J. McCorkel, A. Daw, J. Hair,
D. Jennings, B. McAndrew, D. Rabin

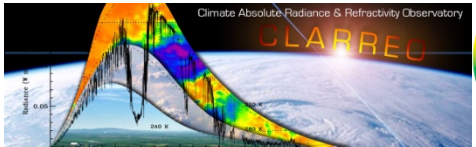
NASA/GSFC

CLARREO SDT Meeting
Greenbelt, MD Jan. 7-9, 2014

CLARREO RS CDS – Overview

Climate-level radiometric accuracy is achievable in laboratory setting

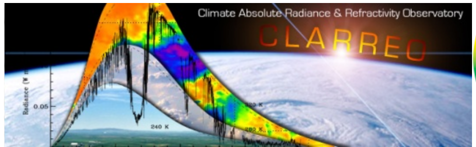
- NIST approaches have been transferred to other laboratories
- Dominant uncertainty in going to orbit is stray light characterization uncertainty
  - Laser-based sources and detector-based standards are key to understanding stray light
  - High-fidelity sensor models will allow transfer of laboratory characterization to orbit
- Must demonstrate:
  - We understand attenuator behavior on orbit
  - Radiometric uncertainties allow data aggregation
  - Polarization assessment can be done as required



CLARREO RS path forward

Key to CLARREO error budget is documentation and demonstration

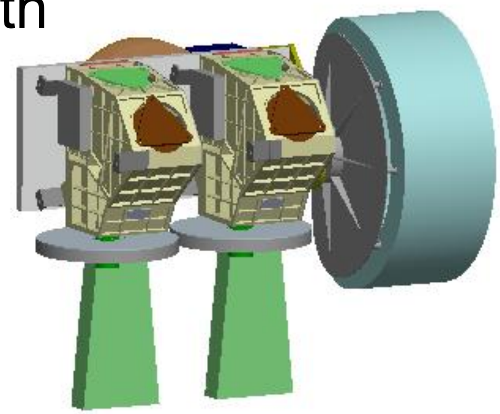
- Documentation is understood as a high priority
  - A recent NIST informal review was a first step
  - Goal is to prioritize efforts to accelerate ability to publish
- Do not envision any technological issues with achieving a 1% reflectance uncertainty
  - Validating 1% is non-trivial
  - Demonstrating achievability on orbit is difficult



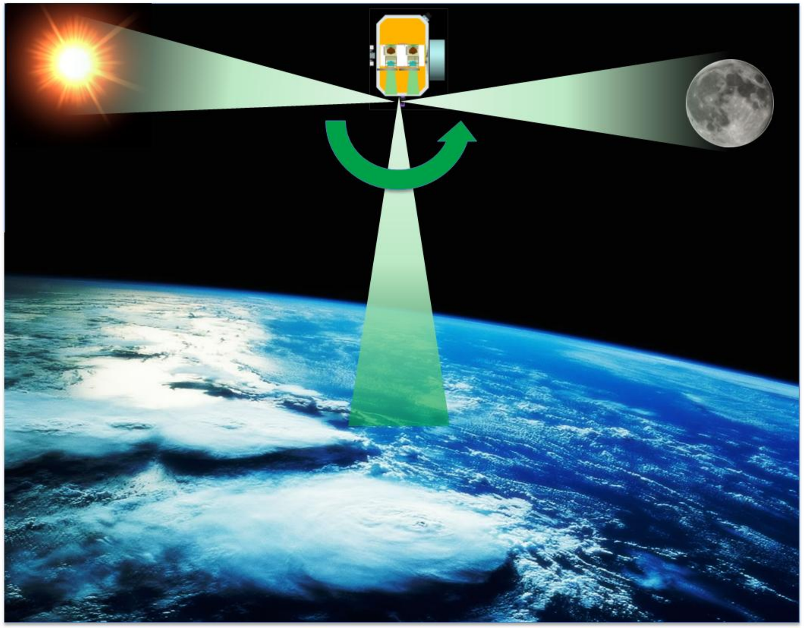
RS Instrument

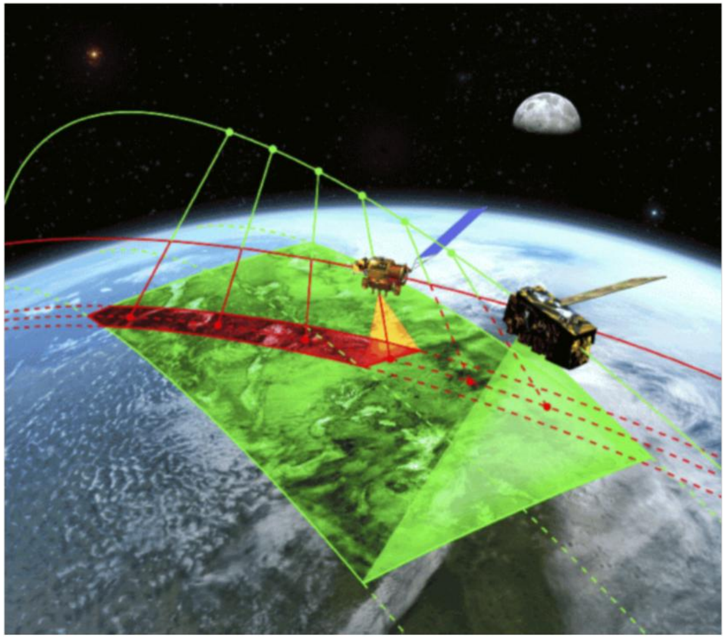
Offner system covering 320 to 2300 nm with 500-m GIFOV and 100-km swath width

Reflectance traceable to SI standards at an absolute uncertainty <0.3%



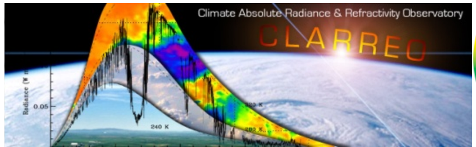
Benchmark reflectance from ratio of earth view to measurements of irradiance while viewing the sun





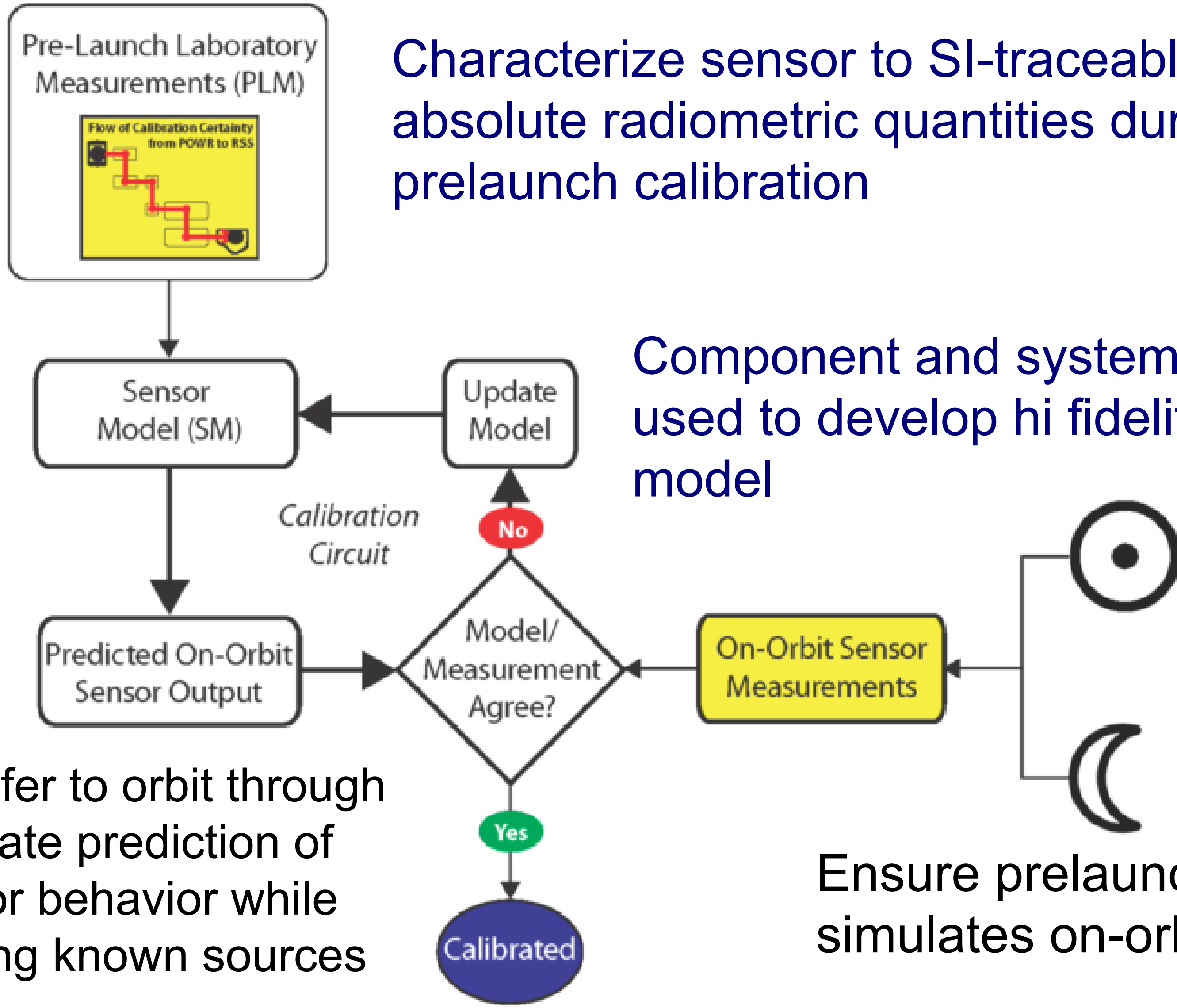
Lunar data provide calibration verification

Inetrcalibration plays a key role in developing climate record



Calibration approach

Characterize sensor to SI-traceable, absolute radiometric quantities during prelaunch calibration



Component and system level data used to develop hi fidelity sensor model

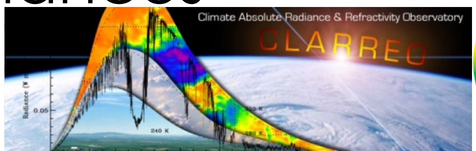
Transfer to orbit through accurate prediction of sensor behavior while viewing known sources

Ensure prelaunch calibration simulates on-orbit sources

LASP’s IIP HySICS

Implements solar cross-calibration approaches to provide on-orbit radiometric accuracy and stability tracking

- *HyperSpectral Imager for Climate Science* the follow-on to a breadboard instrument (G. Kopp is PI)
- Flight test a CLARREO-like hyperspectral imager
  - <0.2% (k=1) radiometric uncertainty
  - <0.13% (k=1) instrumental polarization sensitivity
- Perform two high-altitude balloon flights to demonstrate solar cross-calibration approach and to acquire sample Earth and lunar radiances



HySICS provides CLARREO-like opportunities

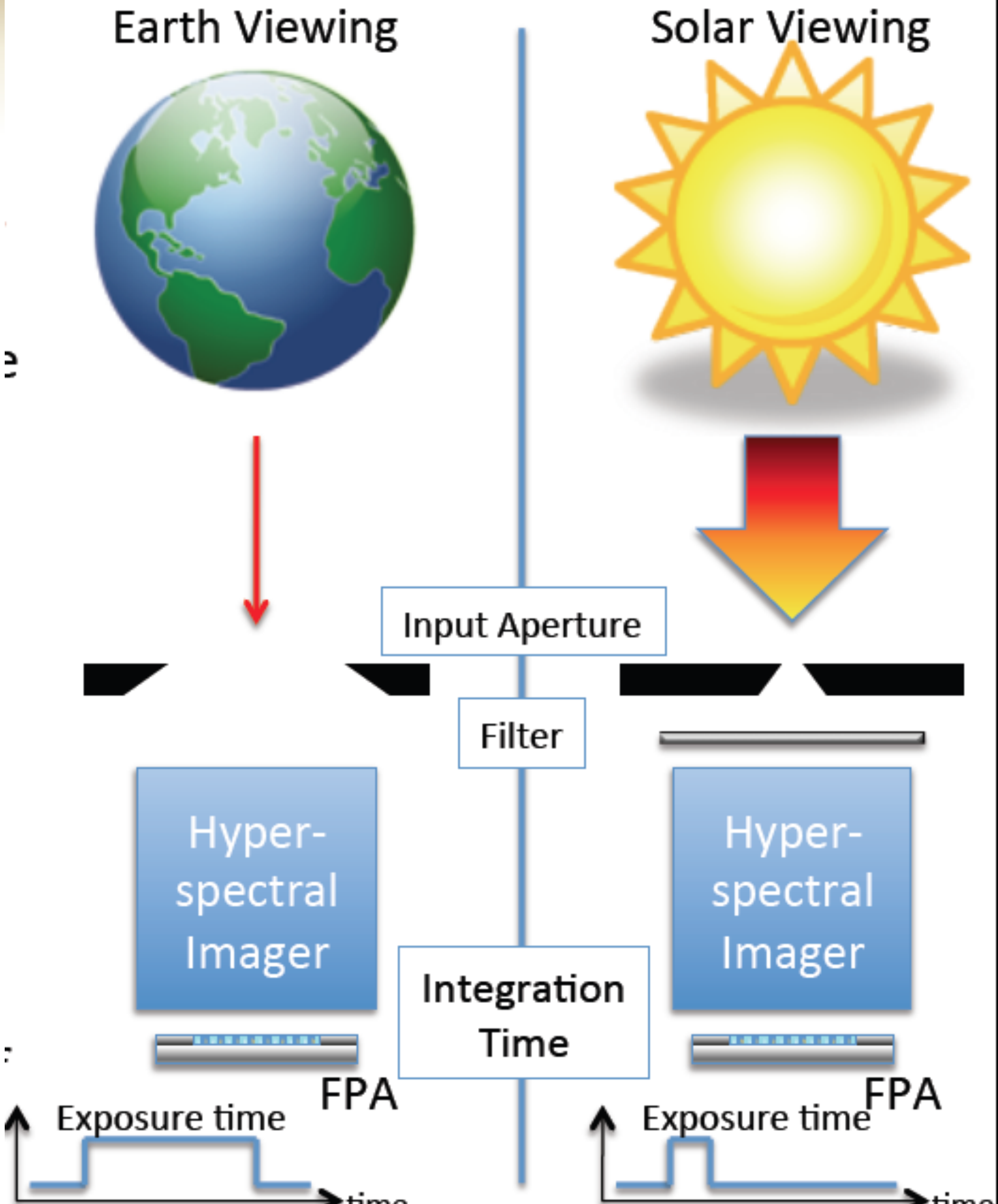
Initial flight in September 2013

- Demonstrate feasibility of acquiring CLARREO reflected solar data with single spectrometer
- Smaller, lower mass instrument
- Solar cross-calibrations under realistic conditions
- Builds on and improves needed ground test equipment
- Environmental testing after initial instrument calibration
  - Vibration tests
  - TVAC testing
  - Post I&T calibration to confirm instrument performance

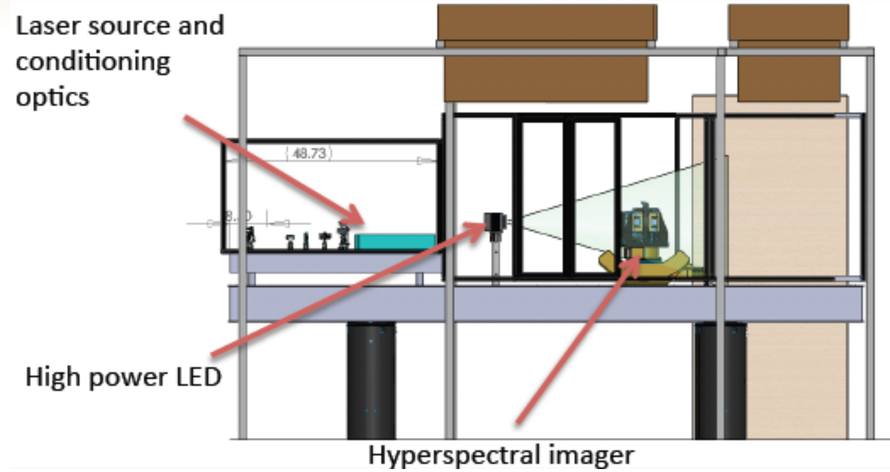
Solar cross-calibration

Showing retrieval of reflectance is key element of HySICS

- Non-trivial measurement because
  - Large difference between solar and terrestrial signals
  - Size of source difference as well
- Breadboard demonstrated feasibility



HySICS Laboratory improvements



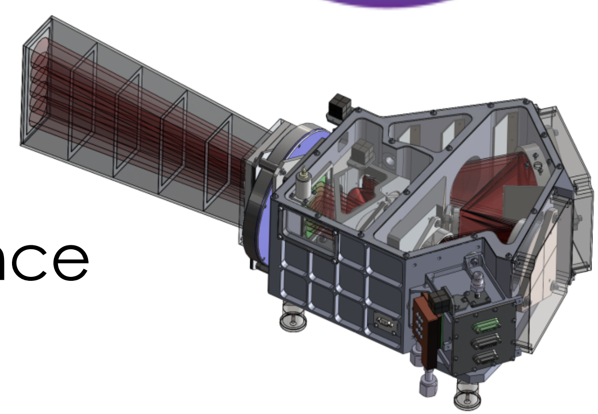
Need to demonstrate that research-level efforts at metrology labs can be transferred to other facilities

- LASP and GSFC both have NIST-supplied traveling SIRCUS and trap detector monitors calibrated by NIST over seven orders of magnitude
- LASP has a cryogenic, electric substitution radiometer
- Uniform, stable white light sources for broadband calibrations
- LASP also has demonstrated a solar disk simulator High power laser adjusts intensity over >5 orders of magnitude

Calibration Demonstration System (CDS)

Reducing risk of achieving on-orbit SI-traceability achieved through CDS

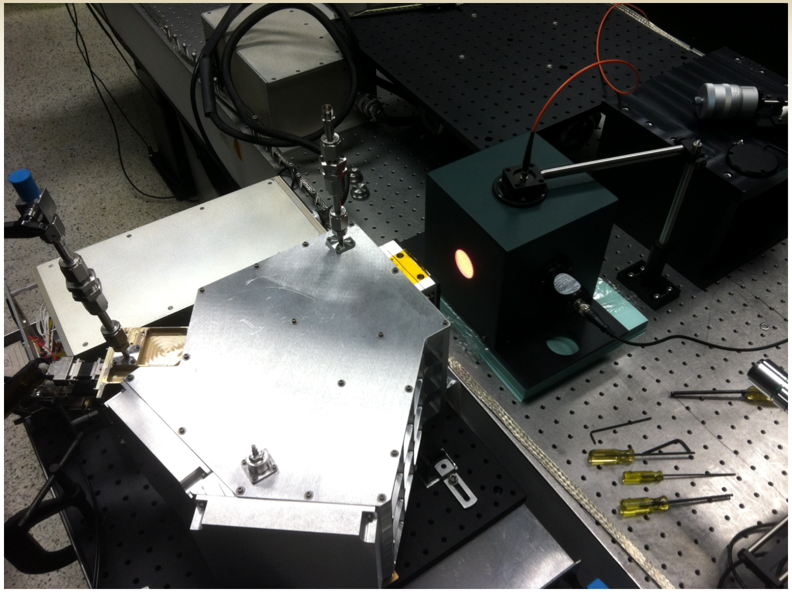
- Reflected solar version is SOLARIS (SOlar, Lunar for Absolute Reflectance Imaging Spectroradiometer)
- Transfer-to-orbit error budget showing SI-traceability
- Technology demonstration for optics, depolarizers, & prelaunch calibration methods
- Field collections to evaluate reflectance retrieval, lunar views, and cross-comparisons with other systems



CDS test plan overview

Test plan follows typical laboratory-based preflight calibrations

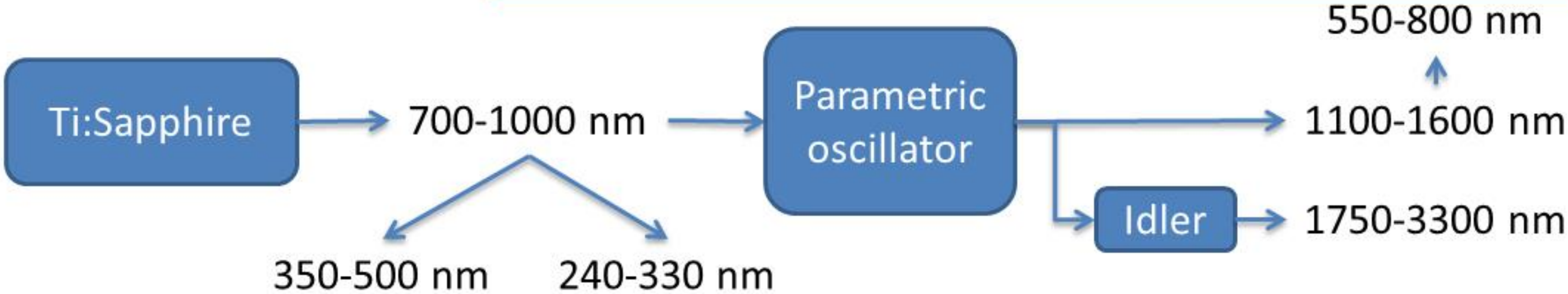
- Emphasis is on radiometric and spectral
- Understanding sensor stray light and optical models is crucial
- Field collections used to understand the on-orbit calibration approaches

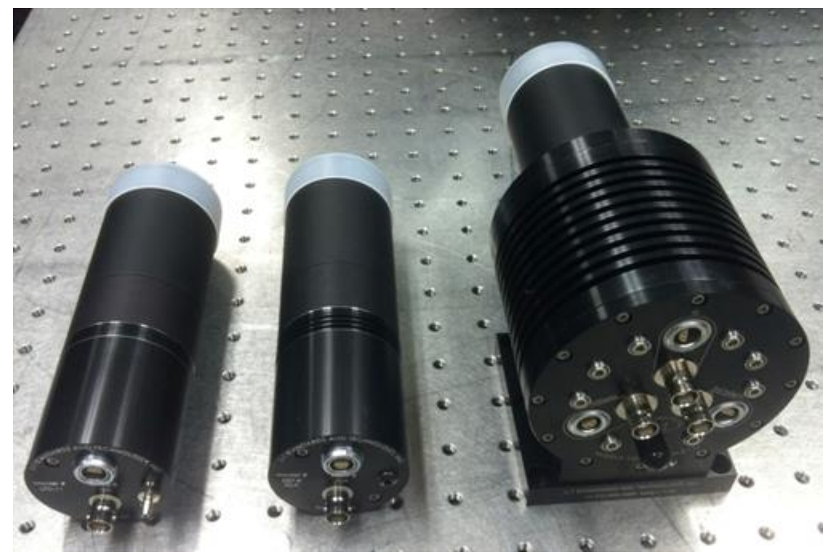


SIRCUS instrumentation

Fancy light bulb: SIRCUS

Spectral irradiance and radiance responsivity calibrations using uniform sources (SIRCUS)





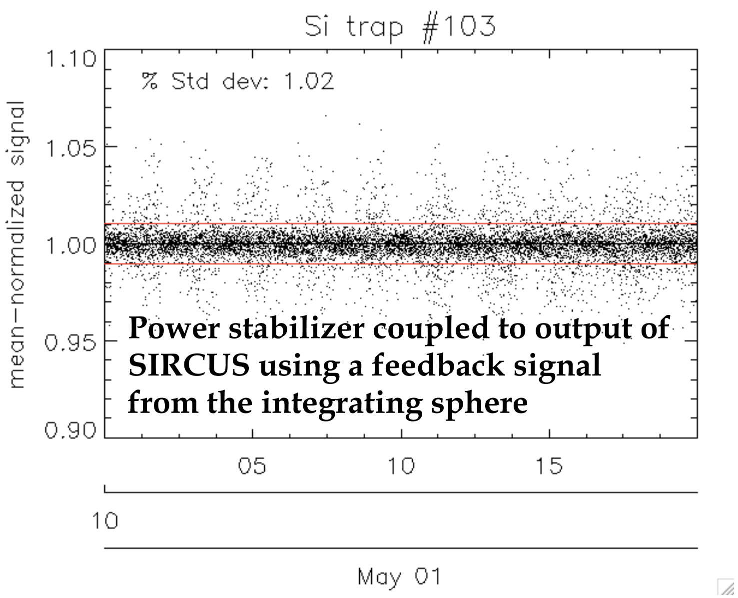
Transfer radiometers

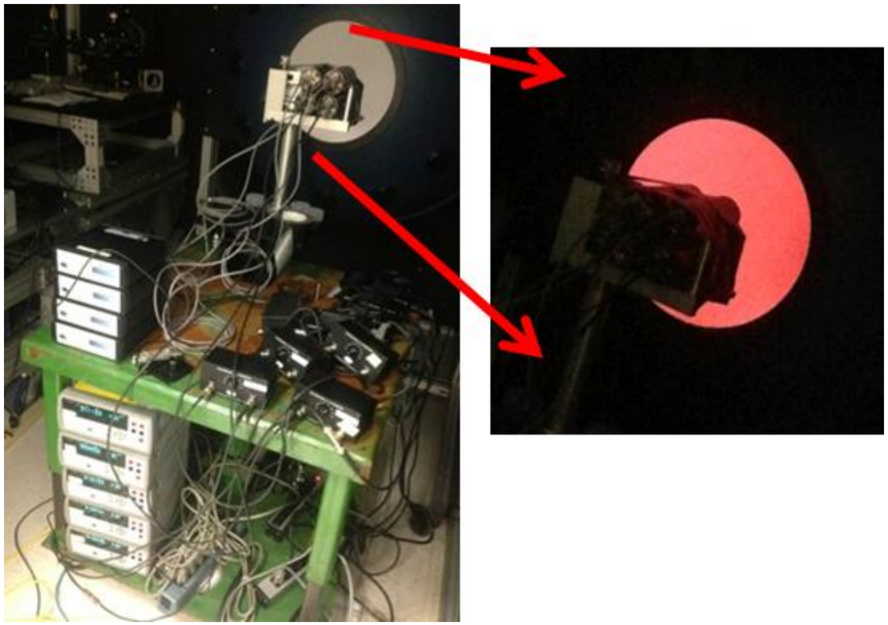
- Key to SIRCUS is use of highly-accurate monitoring radiometers
- 4 Silicon trap detectors have been calibrated at NIST
- 5 InGaAs detectors and 5 sphere (Si, IGA, extended IGA detectors) underwent stability monitoring
- InGaAs detector calibration is being arranged

Source stability and absolute knowledge

Prelaunch, laboratory calibration requires well understood source

- Monochromatic source is monitored by NIST-calibrated transfer radiometers
- Radiometers provide feedback to source laser to stabilize output

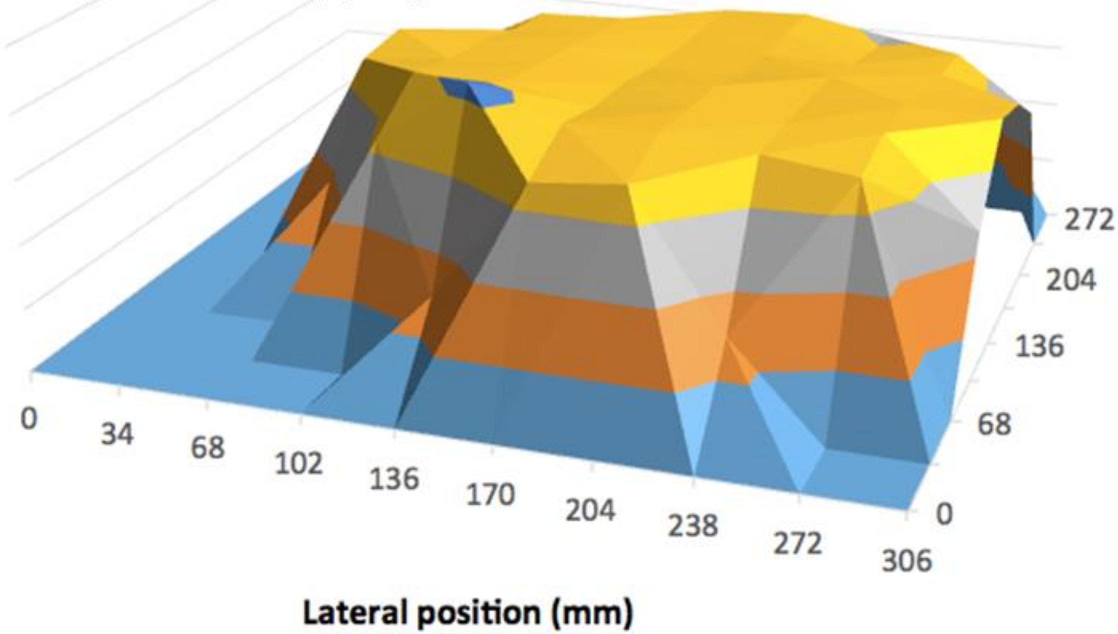


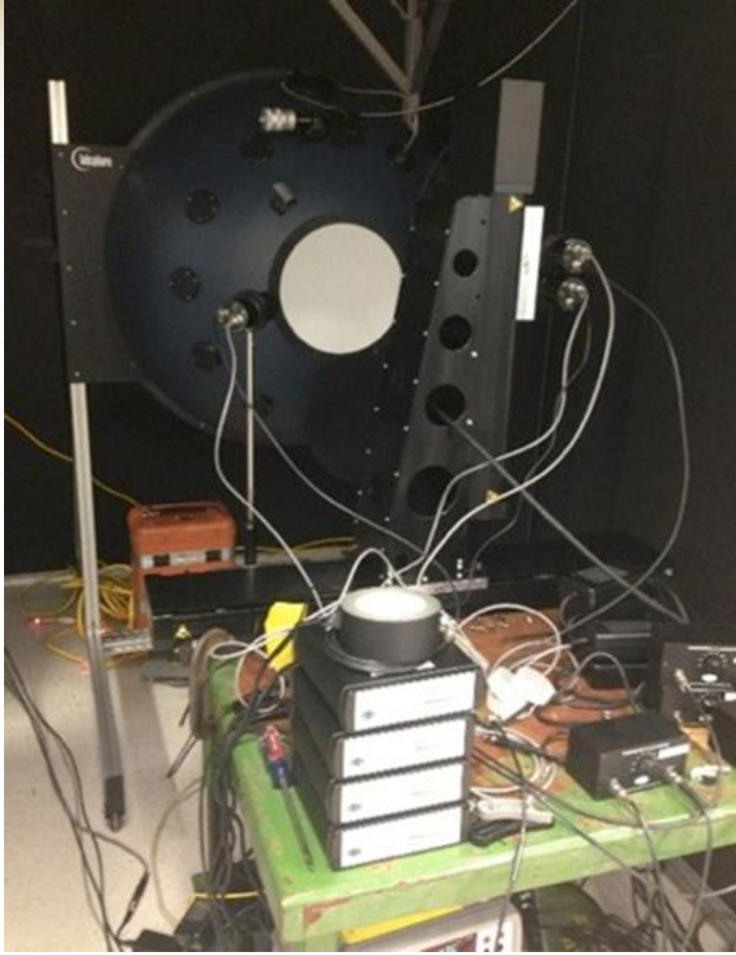


Laser source spatial uniformity

Rely on transfer radiometers to map out radiance source uniformity

Initial results from data taken with the translation and radiometer system used for sphere mapping.





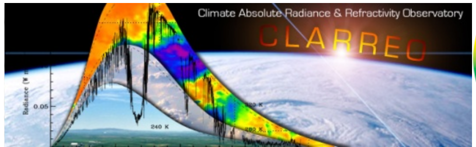
X and Y translation stages with transfer radiometers

Flight-like electronics

SOLARIS detector package allows for large dynamic range but requires linearization

- Results from field tests showed need for improved electronics to optimize collection times
- Flight-like electronics allow for better assessment of error budget
- Funding levels of pre-Phase A have led to delays in implementing the new electronics

Three SOLARIS electronics systems



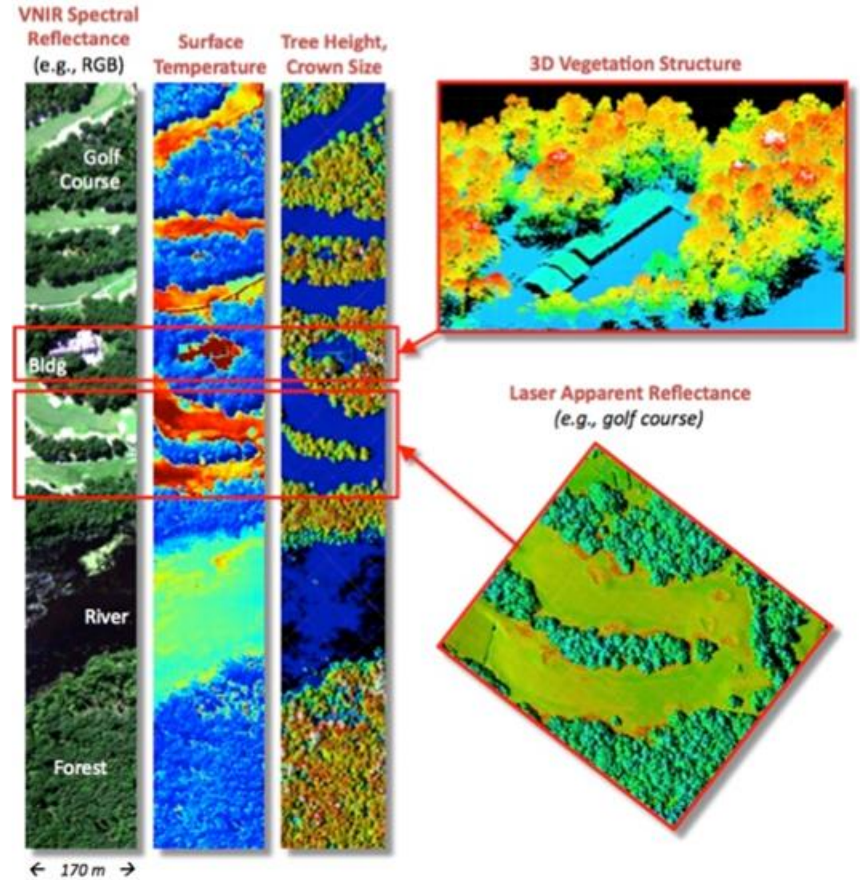
Electronics delay impact

- Mitigated electronics delay by increasing efforts on other work
- Improved blue box
  - Optics and assembly
  - Cooled silicon detector
- Red box
  - Assembly completed
  - MCT detector installed
- "Suitcase" SOLARIS
  - Highly portable version of SOLARIS
  - COTS high resolution detector package
- G-LiHT airborne system used to evaluate SIRCUS methodologies

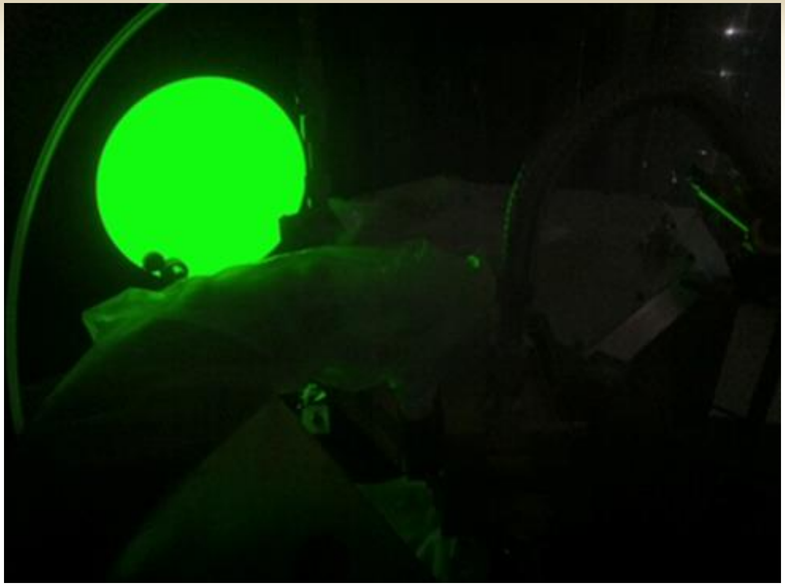
SOLARIS Surrogates - G-LiHT

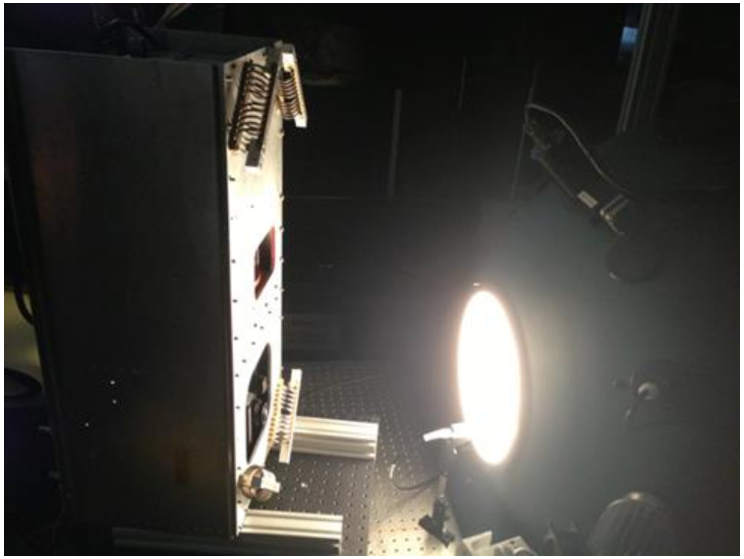
Goddard's Lidar, Hyperspectral, and Thermal Airborne Imaging System

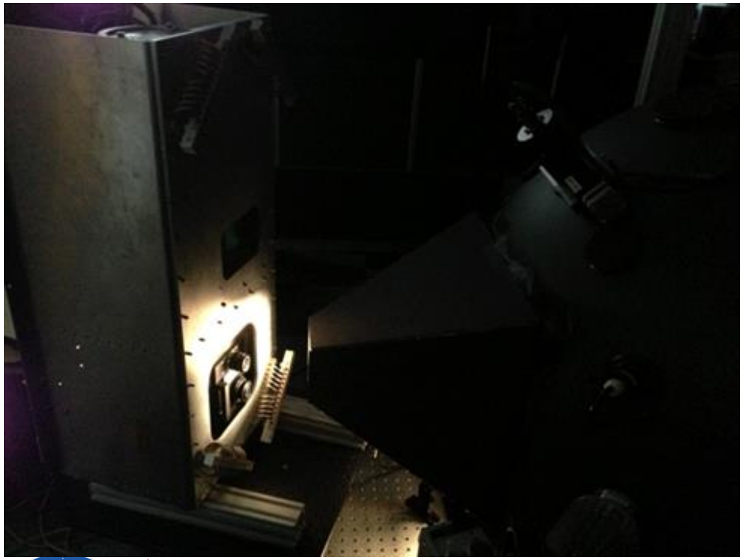
- PI Bruce Cook (GSFC Code 618)
- Vegetation studies
- Three instruments
  - Lidar
  - Thermal imager
  - **VNIR imaging spectrometer**
    - **0.4–1.0 μm**
    - **1.5-nm sampling**
    - **1-m spatial sampling**



G-LiHT preflight calibration



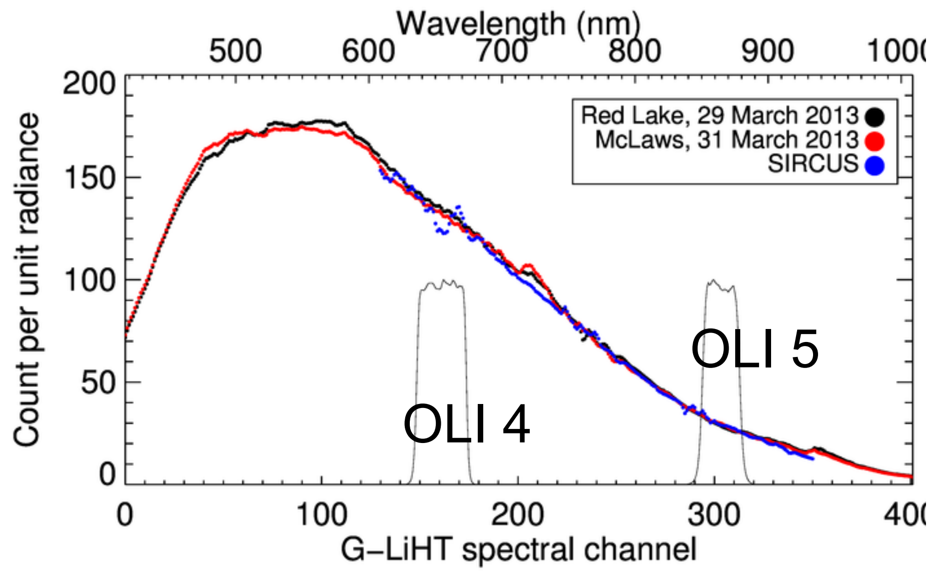


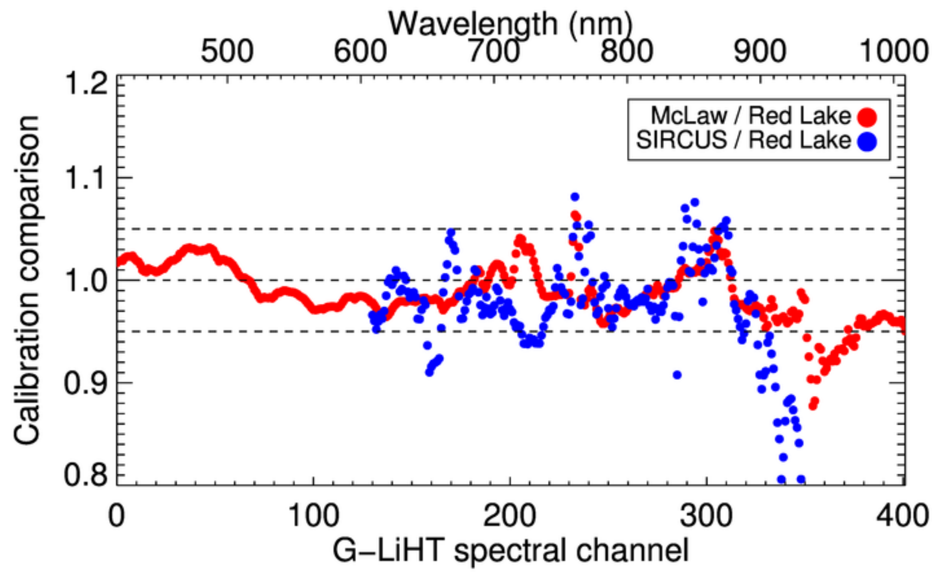


- Calibrating G-LiHT's imaging spectrometer gives further experience with SIRCUS
- Allowed development of calibration approaches coincident with SOLARIS hardware work
- Evaluate sensor effects on calibration
- Transfer of calibration to operational conditions
- Assess sphere stray light


G-LiHT
Landsat 8
Landsat 7
CLARREO/SOLARIS
Surface reflectance
Spectralon reference
Red Lake Playa, Arizona
29 March 2013
http://earthobservatory.nasa.gov/IOTD/view.php?

G-LiHT calibration results

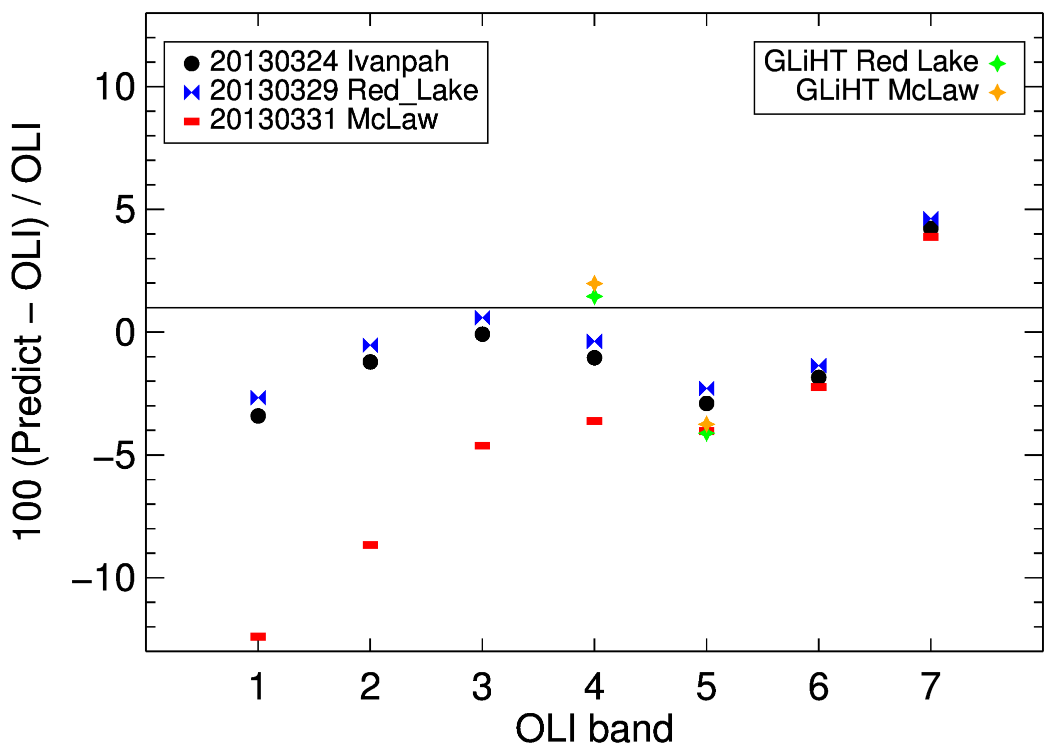


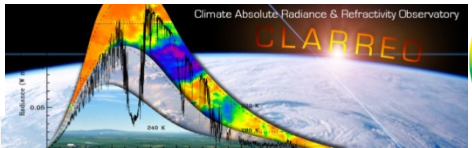


- G-LiHT was calibrated three times
  (1) Laboratory using SOLARIS approaches
  (2) Reflectance-based method at McLaws Dry Lake
  (3) Reflectance-based method at Red Lake
- Compare results to those from Red Lake
- Comparison is in general +/- 5%
  - Shows stability of G-LiHT
  - Shows agreement between laboratory and vicarious

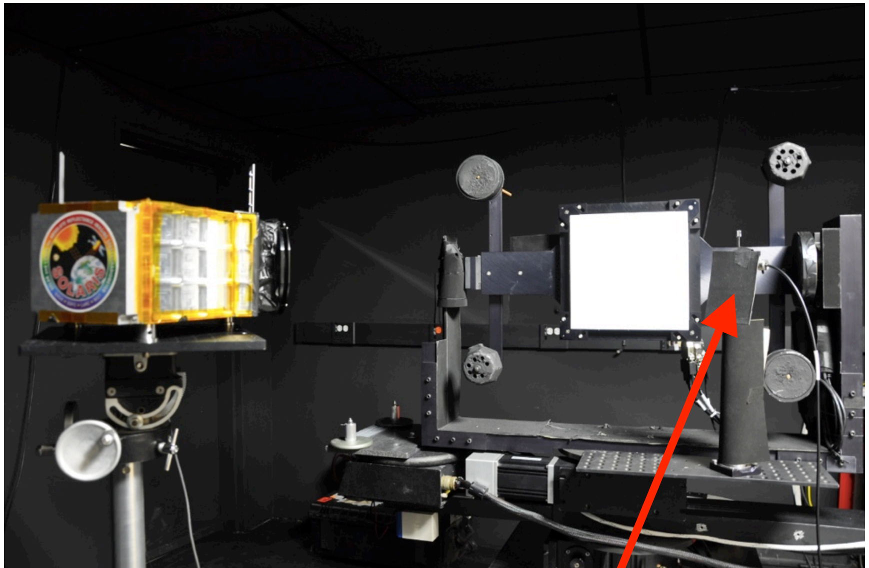
Landsat 8 OLI calibration results

- Compare reflectance-based and G-LiHT results to OLI measurements
- Three sites (Ivanpah Playa, Red Lake, McLaws Dry Lake)
- G-LiHT data convolved to the two OLI bands that match the T-SIRCUS coverage
- Results show agreement to within a few percent



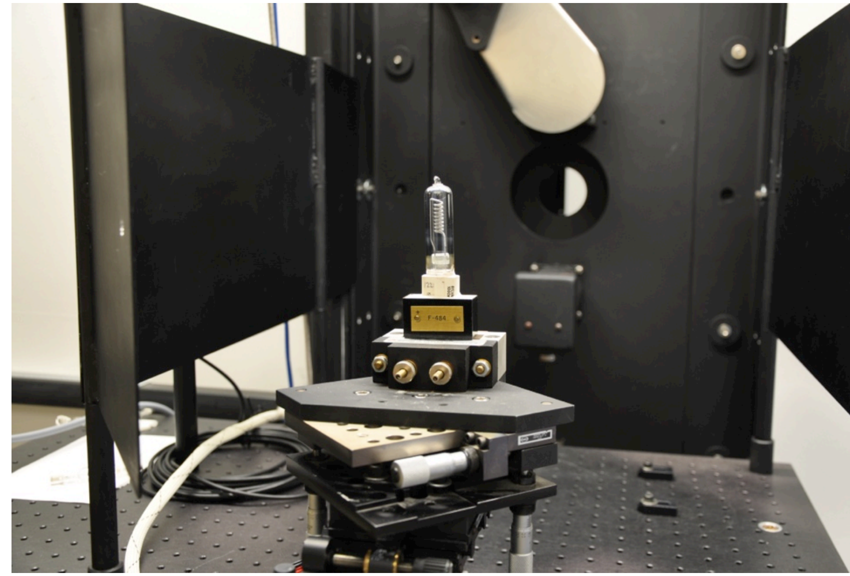


Suitcase SOLARIS stayed behind in Arizona



SuitcaseSOLARIS at 45° to panel

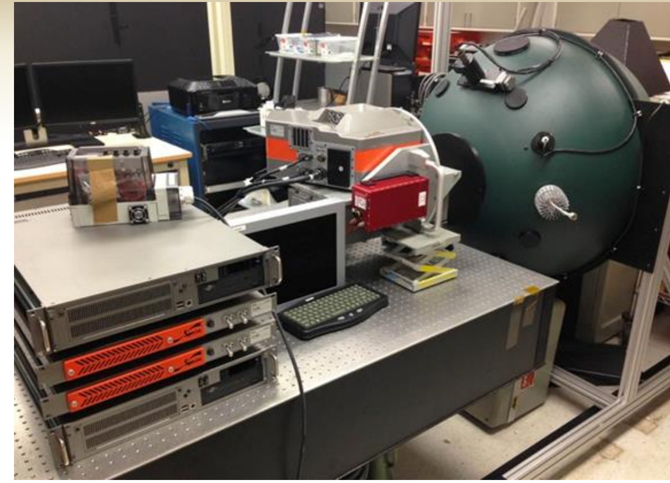
ASD fore optic at 45° to panel



NIST irradiance standard aligned in adjoining room

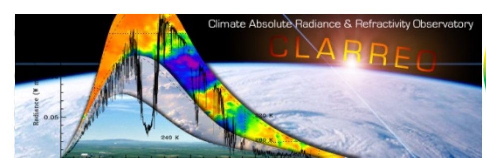
- Primary measurement is radiance calibration of nadir pixels of Suitcase SOLARIS
  - Spectralon diffuser oriented perpendicular to NIST irradiance standard
  - Diffuser characterized by NIST in support of Landsat 8 OLI diffuser characterization
  - 1.5% Total estimated uncertainty (RSS, k=2) at 650nm dominated by NIST source uncertainties and Spectralon panel uncertainties from STARR
- Full-field calibration using a transfer radiometer and a large radiance source

Additional SIRCUS-related projects



GSFC-based IRAD and HyPlant imaging spectrometer

- HyPlant is airborne system for fluorescence measurements
- IRAD is "Evaluation of the performance of an imaging spectrometer against Landsat requirements" J. McCorkel, J. Masek, P. Dabney
  - SOLARIS and SIRCUS provide opportunity to understand best-case scenario
  - Evaluate stray light, out-of-band, SNR characteristics and corrections
  - Provides funding to operate SIRCUS and obtain an airborne suitable focal plane



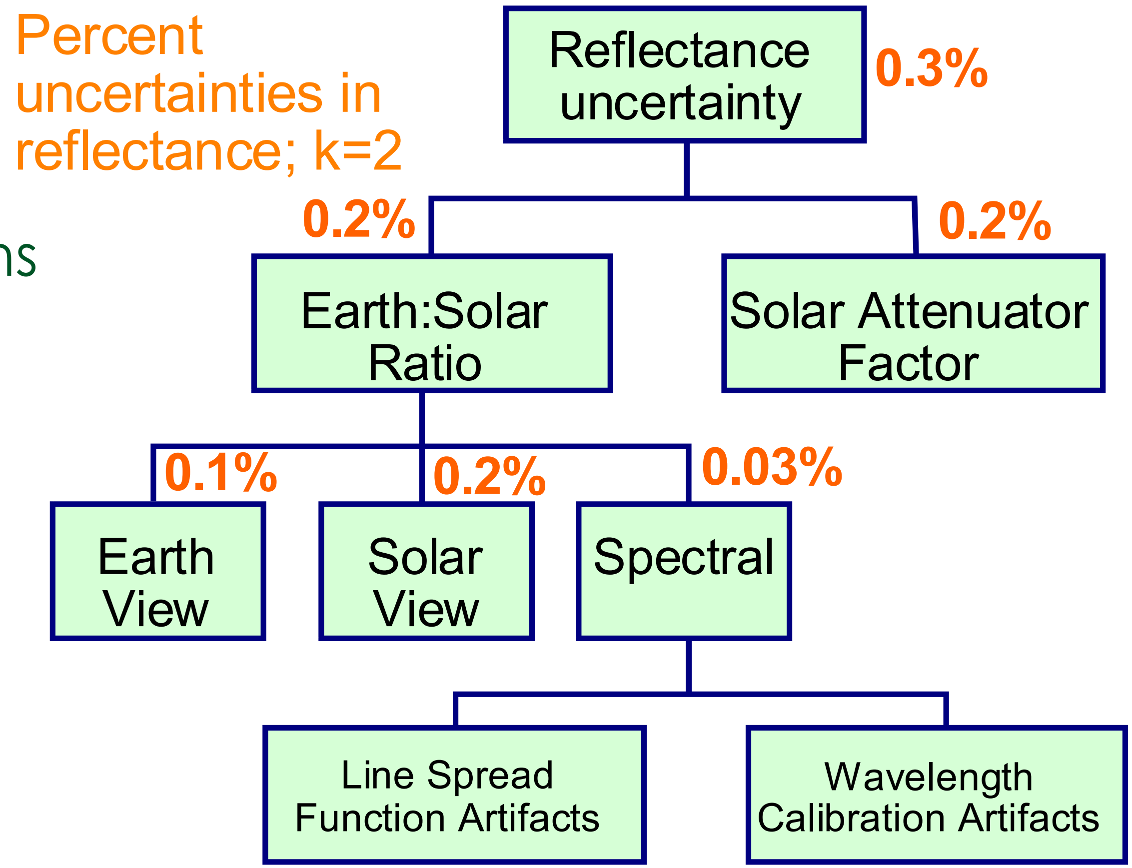
NIST and CLARREO RS

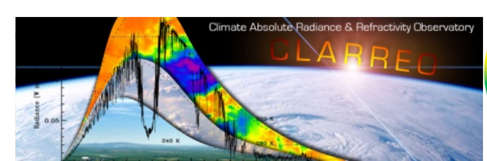
SOLARIS and other sensors have been used to demonstrate key parts of CLARREO calibration

- Collaborative efforts with NIST will continue to be critical
  - ‘Operational’ use of SIRCUS
  - Extension to wavelengths > 1 micrometer
  - Broadband calibration approaches (HIP)
- Laboratory calibration protocols
- Error budget demonstration
- Reflectance retrieval
  - Stray light characterization
  - Instrument model assessment

NIST interaction Nov. 2013

- Presented a tentative error budget to NIST
  - Informational at this point
  - Solicit any suggestions on how to move forward
- Includes NIST-based methods
  - Detector-based transfer radiometers
  - Narrow-band SIRCUS approaches
- Radiometric calibration requirements of RS instrument can be met with currently-available approaches





Earth view budget

0.3% on single measurement

Earth View — 0.1% k=2

- **Radiometric Random**
  - Quantization Noise
  - ROIC Read Noise
  - Electronics Noise
  - Dark Current Noise
  - Near-Field Background Noise
  - Signal Photon Noise
- **Sensor Characteristics** — 0.08%
  - Detector Linearity
  - Integration Time
  - Responsivity and Rel. Gain
    - Optical Efficiency
  - Point Spread Function
  - Line Spread Function
  - Wavelength Calibration
  - Polarization Sensitivity
- **Electronics Offset** — 0.05%
  - Detectors ROIC Analaog
- **Background Offset** — 0.1%
  - Sensor Thermal
  - Scene Thermal
  - Stray Light and Flare
  - Scattered Light
- **Boresight** — 0.05%
  - Jitter

Inclusion of SIRCUS reduces stray and scattered light uncertainties by >1 order of magnitude

Sensor thermal is after dark subtraction

Thermal background important at λ>1.8 μm

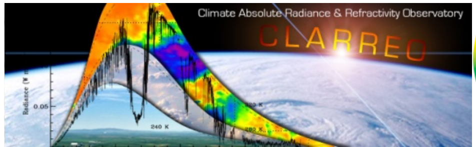
Non-random

Random

Error budget summary

SOLARIS CDS efforts have made significant progress in reducing SI-traceability risk of CLARREO

- 0.3% absolute uncertainty may not be demonstrated during pre-Phase A
  - Funding level limits fidelity of SOLARIS instrument model
  - Equipment improvements may not be feasible
- Demonstrating **path** to 0.3% is the goal
  - Peer reviewed
  - NIST reviewed
- GSFC CLARREO laboratory is currently operating at 3% uncertainty via field spectrometer transfer
- SIRCUS has been implemented for G-LiHT and SOLARIS calibration implying better than 3%
  - Documentation of this effort is still needed
  - Understanding Landsat-8 results also needed



FY14 and beyond

Plans for FY 2014 and beyond concentrate on taking SOLARIS to below the 1% plateau

- Achieving the <1% uncertainty in FY 2014 is at risk
  - Parallel development efforts are limited by lack of personnel
  - Greater susceptibility to hardware failures because of lower procurement funds
  - Improvements to laboratory calibration facilities will be limited or delayed
- Develop and test sensor model development
- Demonstrate error budget for reflectance retrieval
- **Produce a peer-reviewed SI-traceability for CLARREO-like measurements**